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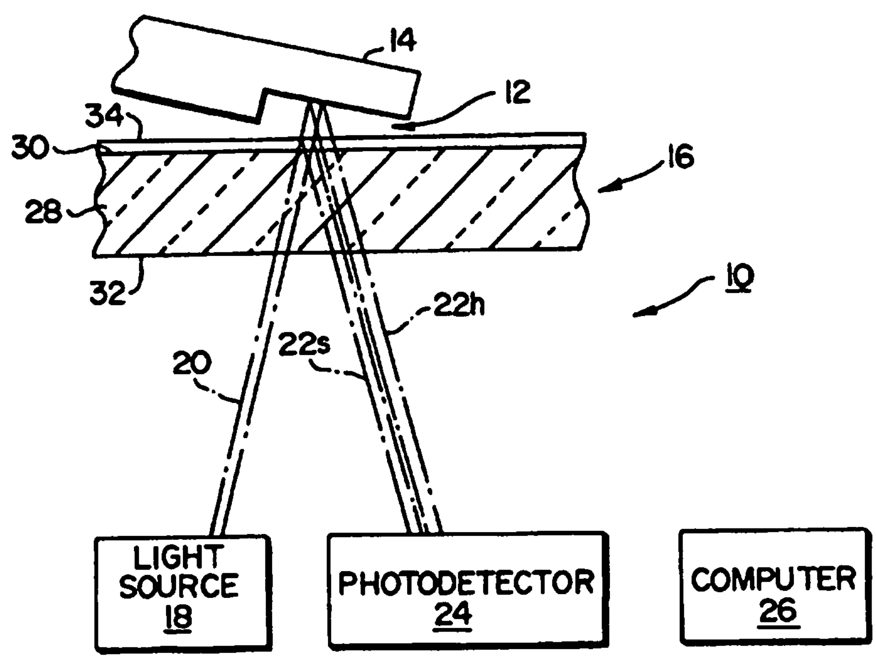

(57) Abstract

A coated transparent interferometric reference (34) for an optical tester (10). In accordance with one aspect of the present invention, the coated reference surface (34) provides improved tribological and optical properties as would be desirable for a disk (16) in an interferometric flying height tester (10).

COATINGS FOR SIMULTANEOUS CONTROL OF TRIBOLOGICAL AND OPTICAL PROPERTIES OF INTERFEROMETRIC REFERENCE SURFACES

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to a coated transparent substrate that is used in a flying height tester which measures the height of an air bearing between a disk and a recording head of a hard disk drive.

2. DESCRIPTION OF RELATED ART

Hard disk drives contain magnetic recording heads which magnetize and sense the magnetic field of a rotating magnetic disk(s). The recording head is integrated into a slider which has aerodynamic features that create an air bearing between the head and the rotating disk. The air bearing prevents contact and corresponding mechanical wear of the recording head.

The sliders are typically tested in a flying height tester before being installed into a hard disk drive assembly. Flying height testers measure the height of the air bearing to insure that the slider complies with manufacturing specifications. Flying height testers typically contain a loader which places each slider adjacent to a rotating transparent disk. A beam of light is directed through the substrate and reflected off of the disk/slider interface. The reflected light creates an interference pattern that is

detected and analyzed by the tester to determine the flying height of the slider.

The transparent disk of the flying height tester is typically constructed from a glass material such as BK-7. The glass is susceptible to scratching and wear particularly when the slider strikes or otherwise makes contact with the disk. Damage in the glass may disturb the interference pattern of the reflected light, reducing the accuracy of the tester. Extensive damage can adversely influence the flying characteristics of sliders. Thus, it would be desirable to provide an optical reference surface that is not susceptible to scratching and wear.

Furthermore, some sliders are designed to operate in or near contact with the disk. The contact may create undesirable wear on the slider or disk during the flying height test. It would therefore be desirable to provide a transparent disk having an optical reference surface that reduced the friction and wear between the disk surface and an adjacent slider.

SUMMARY OF THE INVENTION

The present invention is a coated transparent interferometric reference for an optical tester. In accordance with one aspect of the present invention, the coated reference surface provides improved tribological and optical properties as would be desirable for a disk in an interferometric flying height tester. The disk for example may comprise a diamond like coating that covers a surface of a glass substrate. The coating has a wear resistance which prevents scratching of the underlying glass substrate. The

disk may also have an optical bias layer which compensates for the optical phase shift created by the protective coating. Alternatively or additionally, the disk may have an overlaying lubricant that is applied to the disk or disk coating to reduce friction and stiction.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of the present invention will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, wherein:

Figure 1 is a schematic of a flying height tester having a disk of the present invention;

Figure 2 is a cross-sectional view of an alternate embodiment of the disk;

Figure 3 is a cross-sectional view of another alternate embodiment of the disk.

DETAILED DESCRIPTION OF THE INVENTION

Coatings on glass disks offer a way to improve the tribological properties of the glass surface as well as the interferometer signal produced by a gap between the glass and a second reflective surface of interest. Specific applications of interest include measuring flying height of a disk drive slider on a rapidly spinning glass disk and the measurement of pole-tip recession using a slider positioned at a small gap distance beneath a glass reference flat.

In one embodiment of this invention an amorphous diamond-like-carbon (DLC) layer is deposited on a glass disk. Such a deposition can

introduce a phase shift in the light reflected off the surface. In order to have a control on the amount of phase shift, another material layer of suitable optical constants (e.g., SiO_2 or MgF_2) is deposited under the DLC layer. At any desired wave length in the visible and over a limited range of thickness of DLC, the phase shift on reflection that would exist for DLC alone with no underlay can be effectively nulled out by introduction of an appropriate thickness of lower index material between the DLC and the disk. Thus the DLC coated glass can be made to behave in reflection as a simple bulk dielectric even though a multiple layer coating is actually present. By suitable choice of the index and thickness of the intermediate layer, the phase shift on reflection can be over-compensated so that the phase shift "at contact' occurs well away from an interference minimum.

In another embodiment of the invention, either hydrogenated or nitrogenated DLC coatings can be used for improving the tribological properties of a glass disk. The DLC layer improves the tribology with respect to friction, stiction, corrosion resistance, lubricant adsorption and bonding, and also changes in environmental conditions such as humidity, temperature and gas composition. Such an overcoat has been extensively used for the protection and improved durability of thin film magnetic media. Typically, amorphous hydrogenated DLC coatings have been used in various applications. However, recent studies have shown that nitrogen incorporated in DLC films results in some attractive properties. The internal stresses of the films are found to be lower without much

change in the surface hardness. The optical properties are as also changed. Nitrogenated DLC films have a higher conductivity and may possess a different surface polarity due to the structural changes introduced in the bonding by the presence of nitrogen atoms. The polarity change may improve the lubricant adsorption of the DLC surface when it is applied. The degree of conductivity may be controlled by changing the amount of nitrogen incorporated into the film by changing the process parameters. This may play an important role in reducing the amount of tribo-charging and hence the amount of contamination or wear debris that might accumulate at the interfaces which have tribological interaction. It would also play an important role in reducing the amount of accumulation of charge from other sources in the vicinity of the surface and thus decrease the need for a separate de-ionization unit. When such charge build-up is not eliminated, it may lead to damage of electronic or magnetic sensors in close proximity to the uncoated glass surface due to electro-static discharge (ESD). Sensors such as magneto-resistive sliders (also known as MR heads) and the future GMR (giant magneto-resistive) heads may benefit from the reduced charging associated with a nitrogenated DLC coating. This may be important in future use of these types of heads with flying height testers.

In another embodiment of the invention, improvements in the wear resistance of the glass disk surface may be obtained by coating an ultra-thin layer of lubricant to either the uncoated or a DLC-coated glass surface. This thin layer of lubricant may consist of a single layer or

multiple layers of molecules. Such lubricant layers have been used for thin film magnetic media. However, the thickness of the lubricant should be only be a fraction of the slider flying height (<10%). The implementation of the ultra thin lubricant may be achieved by spin coating, dip-coating, Langmuir-Blodgett (LB) or self assembling mono-layer (SAM) techniques. The bonding of the lubricant molecules to the glass or overcoated surface may be achieved by spontaneous chemical reaction between the surface active head group of the lubricant and the substrate surface. Temperature, UV light, electron beam, plasma or surface treatment or a combination of the above may all impart the degree of bonding.

Referring to the drawings more particularly by reference numbers, Figure 1 shows a flying height tester 10. The flying height tester 10 is typically used to measure the height of an air bearing 12 created between a slider 14 of a recording head and a rotating transparent disk 16. The slider 14 is typically mounted to a loader (not shown) which can allow an operator to place a new head thereon. The flying height tester 10 can therefore test a number of different sliders 14. Although a flying height tester 10 is shown and described, it is to be understood that the disk 16 of the present invention can be configured in other shapes and used in other optical testers such as an optical profilometer that utilizes an optical reference surface.

Used in the flying height tester 10, the transparent disk 16 is rotated by a spindle (not shown). Rotation of the disk 16 induces a flow of air below the slider 14. The recording head 14 has aerodynamic features which induce the

formation of the air bearing 12 between the slider 14 and the rotating disk 16.

The flying height tester 10 further includes a light source 18 which directs a beam of light 20 through the disk 16. The light beam 22h is reflected off of the slider 14 and back through the disk 16. Part of the light beam 22s also reflects off of the interface between the disk 16 and the air bearing 12. The two reflected light beams 22h and 22s create an interference pattern that is detected by a photodetector 24. The photodetector 24 is coupled to a computer 26 that can determine the height of the air bearing 12 from the interference pattern.

The disk 16 has a substrate 28 which has a first surface 30 and an opposite second surface 32. The substrate 28 is typically constructed from a glass material such as BK-7 that is transparent to light. Other optical quality materials may also be used such as quartz, fused silicon or sapphire. However, as it is presently conceived, the tribological and optical coatings of the present invention will alleviate the need to use a more expansive material such as sapphire. The slider 14 is typically constructed from a ceramic material such as AlTiC. A considerable problem with flying height testers as described herein is that the slider material is typically much harder than the glass disk substrate 28. If the slider 14 comes into contact with the glass, the glass will scratch and wear. In accordance with a basic embodiment of the present invention, to protect the glass the first surface 30 of the substrate 28 may be covered with a protective coating 34.

In one embodiment of the present invention, the protective coating 34 is a material which has a hardness that is greater than the hardness of the glass. The protective coating 34 is preferably a diamond-like-carbon (DLC) material. The coating 34 may be applied using sputtering or Chemical Vapor Deposition techniques or other means for applying the DLC material. In general the DLC thickness should be less than about λ/n_c, where λ is the wavelength of light and n_c is the refractive index of the coating. In the preferred embodiment, the thickness of the DLC coating is preferably less than 10nm.

In general, the minimum thickness of the DLC coating 34 will be determined by the mechanical stresses encountered in use. However, the preferable thickness will also depend upon the desired optical properties of the combination disk and coating. Specifically, the coating 34 will induce an additional phase shift in the light beam 22s which reflects from the air-coating outerface, thereby influencing the measured interference pattern. For example, the protective coating thickness may be adjusted to optically bias the interference pattern, thereby achieving high sensitivity to flying height variations at a predetermined flying height (e.g. contact between disk and slider). Alternatively, preferred interlayers may be used to adjust or null the phase offset caused by the protective coating 34. Multi-layer coatings are described in more detail below.

The coating 34 may be a hydrogenated or nitrogenated DLC material or any combination thereof. In addition to providing a hard protective surface the coating 34 may also provide

other favorable tribological properties such as lower stiction, lower friction and corrosion resistance. Additionally, the nitrogen content of nitrogenated DLC may be varied to reduce the amount of tribo-charging and resulting accumulation of debris and contamination on the surface of the disk 16. Reduced tribo-charging will play an important role in testing MR heads. Furthermore, the DLC 34 will also improve the adsorption of a lubricant that may also be applied to the disk 16 as described in more detail below.

Figure 2 shows another embodiment of the disk 16. The existence of the DLC coating 34 may create a phase shift in the reflected light beam 22s which influences the interference pattern and the sensitivity of the tester 10. The disk 16 may include an optical bias layer 36 located between the protective coating 34 and the substrate 28. The bias layer 36 preferably has an index of refraction and a thickness which will adjust the phase shift of the reflected light beam 22s. In one preferred embodiment, the bias layer thickness is adjusted to compensate the phase shift induced by the protective coating 34. The multi-layered disk behaves as a dielectric medium having a net phase shift on reflection adjusted to approximately 180°. The bias layer 36 is preferably a transparent material such as SiO_2 or MgF_2 having an index of refraction lower than the glass substrate 28 with a thickness of 10-30 nanometers. The bias layer 36 may be applied by sputtering, ion-beam deposition or any other means. In another preferred embodiment, the thickness and index of refraction may be selected so that the phase shift biases the interference

pattern to a point of high sensitivity at slider-disk contact.

It will be appreciated that combinations of interlayers may achieve enhanced interferometric properties. As mentioned above, the interlayer may be a single dielectric layer having an index and thickness adjusted to phase bias the interference pattern. Additionally, reflective interlayers may be added to enhance the contrast ratio $\left(\frac{I_{max}}{I_{min}}\right)$ of the interference pattern, and sensitivity over a predetermined air bearing spacing 12. Thus, in addition to protecting the substrate 28, the protective coating 34 prevents damage to a carefully designed and fabricated interferometric reference surface.

Figure 3 shows another embodiment of the disk 16. The disk 16 may have a lubricant 38 applied to the DLC coating 34. The lubricant 38 passivates the surface and reduces the friction and wear between the slider 14 and the disk 16. The lubricant 38 may comprise perfluoropolyether (PFPE) or a mixture of a PFPE with other lubricants applied with known processes such as spin coating, dip coating, Langmuir-Blodgett, or self assembling mono-layer (SAM) techniques. The lubricant 38 may consist of a single layer, or multiple layers of molecules. The lubricated disk 16 may be treated with heat, ultraviolet light, electron beam or other means to bond the lubricant 38 to the underlying disk material.

The transparent disk 16 is periodically cleaned to remove debris and contaminants that may accumulate on the outer surfaces of the disk 16. The disk 16 may be cleaned with a cleaning solution which contains the lubricant 38 so that

the surface of the disk 16 is replenished with residual lubricant by the cleaning process. Typically, such a cleaning/lubricating process will utilize a cleaning solution having a lubricant concentration of less than 10%.

Although attachment of the lubricant 38 to the DLC coating 34 is shown and described, the lubricant 38 can be applied to a disk 16 which does not have the protective coating 34 or the bias layer 36.

In accordance with the present invention, a preferred class of lubricants for application directly to the transparent substrate 28 comprise PFPE lubricants. Preferably, the specific PFPE lubricant should have a refractive index closely matched to the substrate 28. It should also have low surface tension for uniformly wetting the substrate surface, and be non-corrosive (ph 7). While it is believed that many possible PFPE lubricants such as Z-DOL may be used to lubricate the transparent substrate 28, it has been found that Demmum S-200 (Daiken Industries Ltd.) substantially satisfies the aforementioned criteria.

As mentioned above, surface tension and wetting are important considerations for establishing a thin, uniform lubricating layer. It is therefore highly desirable to properly clear the glass disk 16 or transparent substrate 28 before applying the lubricant. A sufficient clearing process may comprise rinsing in a combination of solvents including de-ionized water, ultrasonic clearing, and spin drying. After repeated solvent treatments, the glass disk 16 is exposed to a plasma cleaning process comprising O_2 or more preferably Ozone.

Lubricant is applied to the cleaned substrate 28 by a dipping or gravity process, or by spin coating. In both cases, the lubricant is preferably used in solutions having a concentration to yield lubricating layers typically 1-10 molecular layers thick. To provide solid monolayer bonding between the lubricant and the glass disk 16 (coated or uncoated), a UV curable phosphozene (e.g. X-1P, Dow Chemical) is added to the lubricant solution. After coating the glass disk 16, the lubricant layer is UV cured to achieve good adhesion to the glass surface.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art. For example, although the coatings 34, 36 and 38 are shown on the first surface 30 of the substrate 28, it is to be understood that any combination of the coatings 34, 36 and may also be applied to the second surface 32 of the substrate 28.

What is claimed is:

1. A disk of an optical tester, comprising:
a transparent substrate that has a first surface and an opposite second surface; and,
a coating on said first surface of said transparent substrate.

2. The disk as recited in claim 1, wherein said coating is transparent.

3. The disk as recited in claim 2, wherein said transparent coating has a hardness that is greater than a hardness of said transparent substrate.

4. The disk as recited in claim 2, wherein said transparent substrate is a glass material and said transparent coating is a diamond-like-carbon material.

5. The disk as recited in claim 4, wherein said diamond-like-carbon material is hydrogenated.

6. The disk as recited in claim 4, wherein said diamond-like-carbon material is nitrogenated.

7. The disk as recited in claim 1, wherein said coating is a lubricant.

8. The disk as recited in claim 1, further comprising a null coating located between said transparent substrate and said coating.

9. The disk as recited in claim 3, further comprising a lubricant located on said transparent coating.

10. A flying height tester for a recording head of a hard disk drive, comprising:

a transparent substrate that has a first surface and an opposite second surface;

a coating on said first surface of said transparent substrate, said coating being adjacent to the recording head;

a light source that directs a beam of light through said transparent substrate and said coating and onto the recording head, wherein the beam of light is reflected from the recording head; and,

a photodetector that detects the reflected light beam.

11. The tester as recited in claim 10, wherein said coating is transparent.

12. The tester as recited in claim 11, wherein said transparent coating has a hardness that is greater than a hardness of said transparent substrate.

13. The tester as recited in claim 11, wherein said transparent substrate is a glass material and said transparent coating is a diamond-like-carbon material.

14. The tester as recited in claim 13, wherein said diamond-like-carbon material is hydrogenated.

15. The tester as recited in claim 13, wherein said diamond-like-carbon material is nitrogenated.

16. The tester as recited in claim 10, wherein said coating is a lubricant.

17. The tester as recited in claim 10, further comprising a null coating located between said transparent substrate and said coating.

18. The tester as recited in claim 12, further comprising a lubricant located on said transparent coating.

19. A method for measuring a height of an air bearing between a recording head and a disk, comprising the steps of:

a) spinning a transparent substrate that has a first surface and an opposite second surface, wherein said first surface has a coating;

b) placing a recording head adjacent to said coating, wherein there is created an air bearing between the recording head and said coating;

c) directing a beam of light through said transparent substrate and said coating, wherein the beam of light is reflected off of the recording head;

d) detecting the reflected beam of light; and,

e) computing a height of the air bearing from the reflected beam of light.

20. A method for cleaning a disk of an optical tester, comprising the steps of:

a) applying a cleaning solution which has a lubricant to the disk; and,

b) removing said cleaning solution from said disk, wherein a residual lubricant remains on said disk.

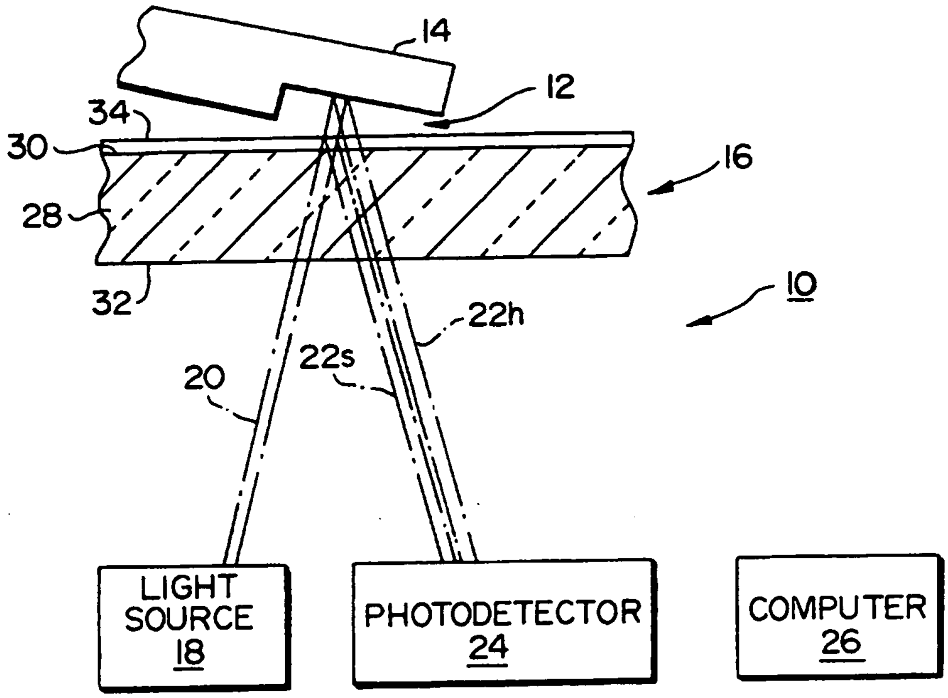

FIG. 1

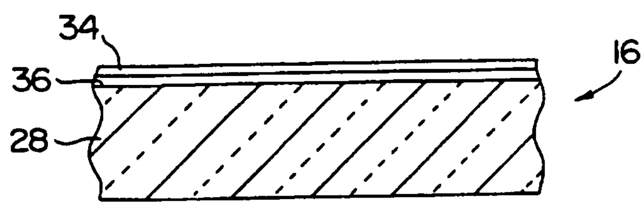

FIG. 2

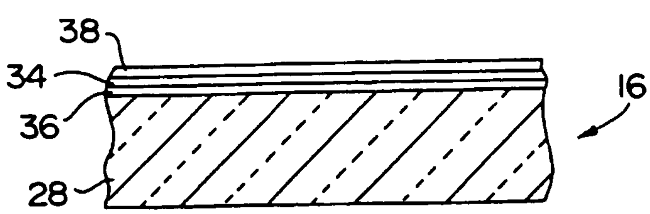

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/12095

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :G01B 09/02
US CL :356/357, 345
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 356/357, 345, 359, 360

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
APS
flying height, coating or coat, protect, lubricant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,473,431 A (HOLLARS ET AL) 05 DECEMBER 1995 (05/12/95), see entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
30 SEPTEMBER 1997	15 OCT 1997

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